

Determining optimal location and size of capacitors in radial distribution networks using moth swarm algorithm

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ABSTRACT

In this study, the problem of optimal capacitor location and size determination (OCLSD) in radial distribution networks for reducing losses is unraveled by moth swarm algorithm (MSA). MSA is one of the most powerful meta-heuristic algorithm that is taken from the inspiration of the food source finding behavior of moths. Four study cases of installing different numbers of capacitors in the 15-bus radial distribution test system including two, three, four and five capacitors are employed to run the applied MSA for an investigation of behavior and assessment of performances. Power loss and the improvement of voltage profile obtained by MSA are compared with those from other methods. As a result, it can be concluded that MSA can give a good truthful and effective solution method for OCLSD problem.

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NOMENCLATURE

Cr	The number of randomly selected control variables among Dim variables
CI, MI	The current iteration and the maximum iteration
Dim	The number of control variables of each solution
g	The gth variable of each solution
GP	Source power at bus 1
$Gr1, Gr2, Gr3$	The number of solutions in group 1, group 2 and group 3
I_c	Current magnitude of the cth branch
I_c^{max}	The maximum current magnitude of each branch
LD	Total load demand
$Levy1, Levy2$	Two Lévy flight distributions
Nb	Number of branches
N_{bus}	Number of buses
N_c	Number of capacitors
PL	Total active power losses
Q_{min}, Q_{max}	The minimum and maximum rated power of capacitor
$R1, R2, R3, R4, R5$	Random numbers distributed uniformly within the interval [0,1]
R_c	Resistor of the cth branch
V_{min}, V_{max}	The minimum and maximum rated voltage of bus
$X_{r1}, X_{r2}, X_{r3}, X_{r4}, X_{r5}, X_{r6}$	Randomly selected solutions from solutions
X_{best}, X_{Gbest}	The best solution in group 1, group 2 and all groups

1. INTRODUCTION

In a power system, lines have one of the important elements in transmitting electric energy from power plants to industrial zones and house holds. There are commonly two-line types such as transmission lines and distribution lines. Here, transmission lines are managed by Transmission Company while other ones are controlled by Electrical Company. However, current running on distribution lines is higher than that of transmission lines because of its low voltage, leading to higher power losses as well as voltage regulation. Also, distribution lines are developing large and being extended. A solution to the mentioned difficulties can be solved by installing distributed generators [1] or adding capacitors at proper locations [2]. In this paper, we only focus on finding the best location and the most appropriate size of capacitors in radial distribution networks. The strategic mission of the considered OCLSD problem is to determine the most suitable location and sizing of capacitors at buses in a radial distribution system in order to decrease power losses, improve the voltage profile, power factor and avoid overloads as presented in a highly efficient method (HEM) [2]. The OCLSD problem has received more attention from researchers and many methods have been proposed. In solving OCLSD problem, a manner implemented in methods has been done in two ways. One is to determine the optimal locations for capacitor placement at candidate buses firstly and then the optimal sizing of capacitors is calculated. Another is simultaneously done a determination both the optimal location and sizing of capacitors. References [3-5] have used a fuzzy technique to find the most suitable positions for capacitor placement while real coded genetic algorithm (RCGA) [3], particle swarm optimization (PSO) [4] and differential evolution (DE) [5] and multi agent PSO (MAPSO) [5] have been applied for sizing of capacitors. Similar to methods above, references [6-11] and [12] have also located the candidate buses by using loss sensitivity factor (LSF) and then the optimal capacitor sizes have been done by time-varying inertia weighting PSO (TVIWPSO) [6], maximum load-ability index (MLI) [7], genetic algorithm (GA) [8], inertia weighting PSO (IWPSO) [9], ant colony optimization (ACO) algorithm [10], modified harmony algorithm (MHA) [11] and artificial bee colony algorithm (ABC) [12]. Dissimilar to the previous methods, teaching learning based optimization (TLBO) [13], hybrid method of chaotic search, opposition-based learning, DE and quantum mechanics (HCODEQ) [14], particle swarm optimization approaches (PSOs) [15] and flower pollination algorithm (FPA) [16] have solved such OCLSD problem by considering locations and size of capacitor as control variables of each solution. On the other hand, voltage enhancement can be reached by using wind turbines and photovoltaic systems [17, 18], network reconfiguration [19-21], and distributed generators [22]. In this paper, MSA is applied to OCLSD problem. The results obtained from MSA are compared with the lately reported results. Moth swarm algorithm (MSA) was evolved by Al-Attar Ali Mohamed in 2017 [23] and employed for solving optimization problems such as combined economic and emission dispatch [24] and image segmentation [25, 26]. In summary, the novelty and contribution of the paper are as follows:

- The first application of MSA for different case of installing capacitors in radial distribution network
- Demonstration of the effectiveness of the number of capacitors for voltage enhancement
- Show a detail of MSA procedure for updating new solutions
- Successfully apply MSA for solving OCLSD problem
- MSA can reach higher quality solutions than other ones.

2. MODEL OF THE OCLSD PROBLEM

2.1. Objective function

Connecting series capacitors or parallel capacitors to the buses of distribution system can significantly reduce total active power losses as well as enhance to the operation stability of the power system. So, minimizing total active power losses (PL) is a key duty in addressing OCLSD problem. Its mathematical formula is given by

$$\text{Minimize } PL = \sum_{c=1}^{Nb} I_c^2 \times R_c \quad (1)$$

2.2. Constraints

2.2.1. Constraints of balancing power system

In distribution system, sum of total load demand and active power losses in lines must be equal to generation power as follows:

$$GP = LD + PL \quad (2)$$

2.2.2. The voltage restriction

The voltage at buses is limited by its lower bound and upper bound below:

$$V_{\min} \leq V_i \leq V_{\max}; i = 1, \dots, N_{bus} \quad (3)$$

2.2.3. Capacitor size restriction

Selecting size of capacitors for connecting to distribution system can reduce power loss or lead to over compensation. Such over compensation not only make power loss extra but also partly impacts on the stability of the system. In this paper, capacitors' size and location are selected to be control variables mean while size is a continuous variable but location is a discrete variable. Size of capacitor must be restricted by the minimum and maximum rated power of capacitor as the following in equality:

$$Q_{\min} \leq Q_k \leq Q_{\max}; k = 1, \dots, N_c \quad (4)$$

2.2.4. Restriction of branch current

The current running on branches is equal or smaller than the maximum current of conductor that can be subjected. It is presented as in (5),

$$|I_c| \leq I_c^{\max}; c = 1, \dots, Nb \quad (5)$$

3. METHOD

3.1. Moth swarm algorithm

In MSA [23], the optimal solution of the considered problem related to a light source of the moon is considered as the best moth swarm position and its fitness is the luminescence intensity of the moon. From an initial moths in population Gr , they are assigned three groups with $Gr1$, $Gr2$ and $Gr3$ by basing on their calculated fitness. In which, moths in $Gr1$ are called Path finders that take on finding the light sources to direct the swarm, those from $Gr2$ are named Prospectors that find the food according to the positions determined by Pathfinders and those from the last group are called on lookers that exploit the food source found by Prospectors. The whole operation of these groups has been respectively implemented in three phases below:

3.1.1. Reconnaissance phase:

In the first phase, three popular techniques such as the mutation, adaptive crossover and selection techniques are used for updating new positions of Pathfinders to avoid falling into local search zones. The formulas of these techniques are formed as shown in (6), (7) and (8) respectively.

$$S_s = X_{r1} + Levy1 \cdot (X_{r2} - X_{r3}) + Levy2 \cdot (X_{r4} - X_{r5}); s \in \{1, \dots, Gr1\} \quad (6)$$

$$Z_{s,g} = \begin{cases} X_{s,g} & \text{if } g \in Cr \\ S_{s,g} & \text{if } g \notin Cr \end{cases}; g = 1, \dots, Dim \quad (7)$$

$$X_s = \begin{cases} X_s & \text{if } Fitness(Z_s) \geq Fitness(X_s) \\ Z_s & \text{if } Fitness(Z_s) < Fitness(X_s) \end{cases} \quad (8)$$

For implementing the work in the transverse orientation phase, X_{Light} with Gr solutions are established. Each solution in X_{Light} is randomly selected from the kept solutions of Gr dependent on the probability value of solutions P_s . This probability value is given by,

$$P_s = \frac{Fit_s}{\sum_{s=1}^{Gr} Fit_s} \quad (9)$$

where Fit_s is the luminescence intensity factor of each solution s it is calculated from the objective function value $Fitness_s$ as presented in (10).

$$Fit_s = \begin{cases} \frac{1}{1 + Fitness_s} & \text{for } Fitness_s \geq 0 \\ 1 + Fitness_s & \text{for } Fitness_s < 0 \end{cases} \quad (10)$$

3.1.2. Transverse orientation phase:

From information about the luminescence intensity shared by Pathfinders, Prospectors fly according to a logarithmic spiral path to update their position. The process for updating Prospector's position is shown as (11),

$$X_i = |X_i - X_{Light,i}| \cdot e^{\theta} \cdot \cos 2\pi\theta + X_i; i = Gr_1 + 1, \dots, Gr_1 + Gr_2 \quad (11)$$

where θ is a randomly selected number in range of $(-1 - (CI/MI), 1)$ [17]; Gr_2 is calculated by:

$$Gr_2 = \text{round} \left((Gr - Gr_1) \times \left(1 - \frac{CI}{MI} \right) \right) \quad (12)$$

3.1.3. Celestial navigation phase:

In the last phase, Onlookers are divided in two small groups. Moths in two small groups are updated their new positions by using the following (13) and (14),

$$X_k = X_k + X_{r6} + [R_1 \cdot X_{best} - R_2 \cdot X_k]; k = Gr_2 + Gr_1 + 1, \dots, Gr \quad (13)$$

$$X_k = X_k + R_3 \cdot X_{r6} + \left(1 - \frac{CI}{MI} \right) \cdot R_4 \cdot (X_{light,k} - X_k) + \left(\frac{2CI}{MI} \right) \cdot R_5 \cdot (X_{best} - X_k);$$

with $k = Gr_2 + Gr_1 + 1, \dots, Gr$ (14)

3.2. The implementation of MSA to OCLSD problem

Two parameters of OCSA problem such as the location and sizing of capacitors are considered as the control variables of MSA. These variables are a solution corresponding to a moth. The process for executing MSA to OCSA problem is described as Figure 1 (see in appendix). Such figure displays the flowchart of MSA.

4. NUMERICAL RESULTS

The method applying MSA has been tested on distribution system of 15 buses for solving the optimal capacitor placement problem. The single line diagram of such system and its data are taken from [5]. The process for calculating MSA method is implemented on a PC with processor Core i5 – 2.2 GHz and 4GB of RAM. In addition, after determining location and size of capacitors, power flow method is applied to calculate branch currents and then power loss is obtained by using (1). Population size and the number of maximum iterations are set to 30 and 100. Fifty trial runs are implemented for MSA. Total active power loss objective function is employed to assess the ability of MSA with four different cases regarding the placement of different location of capacitors. The four cases are described as follows:

- Case 1: Considers a connection of two capacitors at two different buses
- Case 2: Investigates an installation of three capacitors at three different buses
- Case 3: Studies the installation of four capacitors at four different buses
- Case 4: Inspects five capacitors at five different buses.

4.1. Power loss optimization

The active power loss of the investigated system is 61.8kW [2]. This value can be reduced by connecting capacitors. In power loss reduction, the determination of accurate location and suitable size of capacitors has played a very important role. If this process is incorrect, it leads to over compensation. For this reason, MSA has been applied in determining the optimal location and sizing of capacitors. Results obtained by MSA along with other methods for all investigated cases are shown in Tables 1-8. Tables 1-4 show the optimal position and size of capacitors of MSA and other methods. For case 1, the optimal locations found by MSA are bus 4 and bus 6, those for case 2 are buses 4, 6 and 11. Those for case 3 are buses 4, 6, 9 and 11, and those from case 4 represent buses 4, 6, 7, 9 and 11. The optimal capacitor sizes given by MSA for case 1 are

701.65 kVAR and 438.36 kVAR, those for case 2 are 488.25 kVAR, 408.08 kVAR and 300.10 kVAR, those for case 3 are 457.09 kVAR, 377.03 kVAR, 139.05 kVAR and 284.76 kVAR and those for case 4 are 460.75 kVAR, 156.03 kVAR, 209.75 kVAR, 152.14 kVAR and 284.19 kVAR.

Table 1. The optimum sizing and location of capacitors of methods for case 1

Bus no		3	4	6
Qc (kVAR)	HEM [2]	805	0	388
	TVIWPSO [6]	871	0	321
	ACO [10]	0	630	410
	MSA	0	701.65	438.36

Table 2. The optimum sizing and location of capacitors of methods for case 2

Bus no		2	4	5	6	11	15
Qc (kVAR)	GA [8]	750	0	300	0	150	0
	MHA [11]	0	0	0	350	300	300
	MSA	0	488.25	0	408.08	300.1	0

Table 3. The optimum sizing and location of capacitors of methods for case 3

Bus no		4	6	9	11	13	15
Qc (kVAR)	IWPSO [9]	450	450	0	0	150	150
	MSA	457.09	377.03	139.05	284.76	0	0

Table 4. The optimum sizing and location of capacitors of methods for case 4

Bus no		4	6	7	9	11	15
Qc (kVAR)	PSO [4]	274	193	143	0	267	143
	DE [5]	345	264	143	0	300	143
	MSA	460.75	156.03	209.75	152.14	284.19	0

Tables 5-8 show a comparison between results obtained from MSA and other methods in term of a power loss, a reduction of power loss (*RPL*) in kW and in (%). Column 3 of these tables shows that the power losses value gotten by MSA is always better than other methods for all cases. That of MSA is 32.31kW for case 1, 30.34kW for case 2, 29.90 kW for case 3 and 29.75 kW for case 4 whilst that of others is from 32.6 kW to 36.81 kW for case 1, from 31.12 kW to 31.67 kW for case 2, 30.3 kW for case 3 and from 30.55 kW to 30.96 kW for case 4. As valuing the reduction of power loss, MSA can reach less power loss than other methods by from 0.29 kW to 4.5 kW for case 1, from 0.78 kW to 1.33 kW for case 2, 0.4 kW for case 3 and from 0.8 kW to 1.21 kW for case 4. The reduction of power loss corresponding to the improvement percentage of MSA over other ones is presented in column 5 of Tables 5-8. From these comparisons, it can be seen that MSA can reach better optimal result than other methods for all cases. In addition, the voltage at buses is also presented in Figure 2. Such figure shows the improvement of voltages in cases with or without installing capacitors.

Table 5. Comparison between results obtained from MSA and other methods for case 1

Method	Total KVAR added	Power loss kW	RPL In kW	RPL In %
HEM [2]	1193	32.6	0.29	0.89
TVIWPSO [6]	1192	32.7	0.39	1.19
ACO [10]	1040	36.81	4.5	12.22
MSA	1140	32.31	-	-

Table 6. Comparison between results obtained from MSA and other methods for case 2

Method	Total KVAR added	Power loss kW	RPL In kW	RPL In %
GA [8]	1200	31.67	1.33	4.20
MHA [11]	950	31.12	0.78	2.51
MSA	1196.431	30.34	-	-

Table 7. Comparison between results obtained from MSA and other methods for case 3

Method	Total KVAR added	Power loss kW	RPL In kW	RPL In %
IWPSO [9]	1200	30.3	0.4	1.32
MSA	1258	29.90	-	-

Table 8. Comparison between results obtained from MSA and other methods for case 4

Method	Total KVAR added	Power loss (kW)	RPL In kW	RPL In %
PSO [4]	1020	30.55	0.8	2.62
DE [5]	1195	30.96	1.21	3.91
MSA	1263	29.75	-	-

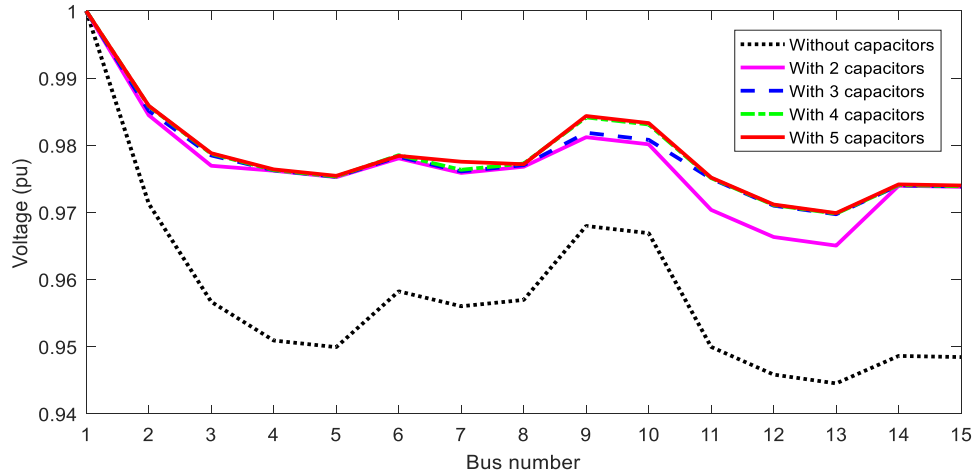


Figure 2. The voltage improvement with and without installing capacitors

4.2. Discussion

The number of capacitors installed onto radial distribution system has significant impact on reducing the power loss as well as improving the quality of voltages at buses in the radial distribution systems. The selection of capacitor number needs to be calculated and analyzed carefully. For this view, Figures 3 and 4 have been plotted to show an alteration of power loss values and improvement of voltages with different numbers of installed capacitors. As shown in Figure 3, the value of power loss decreases from 32.31 kW to 29.75 kW corresponding to from case of added two capacitors to case of added four capacitors. On the other hand, Figure 4 sees voltage is also highly improved, namely from 0.965 pu corresponding to two-capacitor installation to 0.9699 pu corresponding to five-capacitor installation.

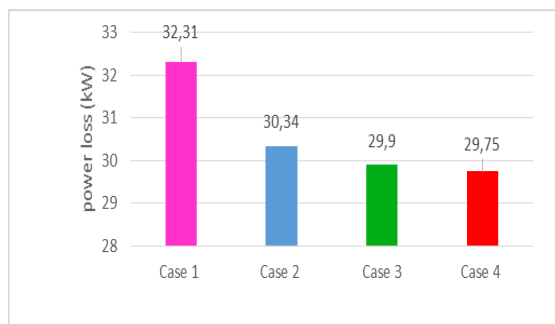


Figure 3. The change of power loss value by adding number of added capacitors

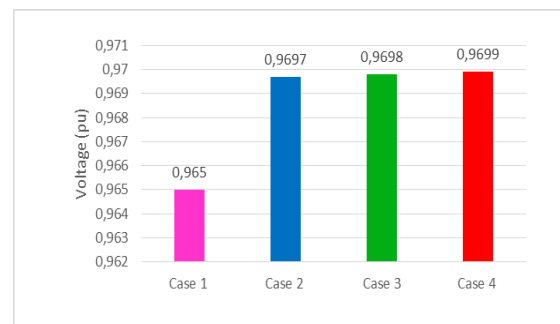


Figure 4. The improvement of voltage by number of added capacitors

5. CONCLUSION

In this research, MSA is recommended for determining the position and sizing of capacitors in the standard distribution system with 15 buses. Results from using MSA show that the power losses are downed up 29.49 kW by adding capacitors at 2 buses, 31.46 kW by adding capacitors at 3 buses, 31.9 by adding capacitors at 4 buses and 32.05 kW by adding capacitors at 5 buses. In addition, the voltage at buses compared between uncompensated system and compensated system are also improved. Namely, the voltage improvement is 0.0205 pu for case 1, 0.0252 pu for case 2, 0.0253 pu for case 3 and 0.0254 pu for case 4. In result comparison with other methods, it indicates that MSA can reach better optimal solutions with less

power loss for all cases. From here, it is possible to infer that the method is an effective method for solving OCLSD problem. In addition, MSA can be applied in future work for determining optimal parameters of STATCOM with the purpose of voltage profile enhancement.

APPENDIX

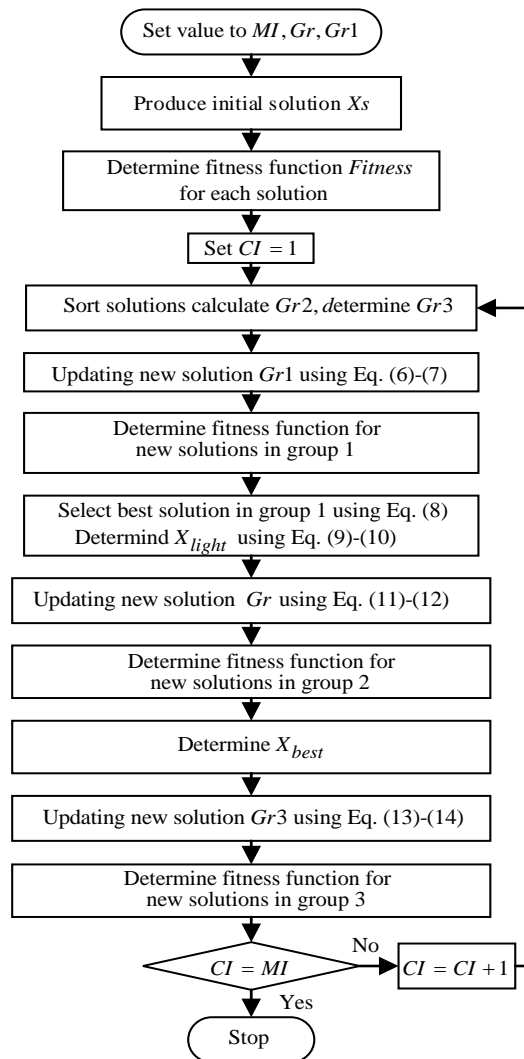


Figure 1. The flowchart of MSA

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